DMIC

review OF RECENT DEVELOPMENTS

Aluminum and Magnesium

D. N. Williams • September 29, 1971

HIGH-STRENGTH POWDER-METALLURGY ALLOYS

Additional information has been received describing a program underway at Alcoa Research Laboratories to develop high-strength powder-metallurgy aluminum alloy products.(1) Laboratory-scale alloy-development and process-development studies performed in earlier phases of this program have been described in previous reviews in this series. This program has now progressed to an early scale-up stage in which preparation of a variety of alloy products is planned using compacted billets weighing up to 170 pounds for a more extensive evaluation of alloy properties. Products to be prepared for evaluation will include hand forgings, die forgings, extrusions, plate and sheet. Several high-strength conventionally cast alloys will be included in the scale-up program for comparison purposes.

At least three powder-metallurgy alloys will be examined in this program: (1) Al-6.5Zn-2.3Mg-1.5Cu, (2) either Al-8.0Zn-2.5Mg-1.0Cu-1.6Co or Al-8.0Zn-2.5Mg-1.0Cu, and (3) a composition expected to show improved toughness and reduced quench sensitivity to be selected from a group of high-purity alloys presently being evaluated. The scale-up program will include additional studies of process variables.

FURTHER DEVELOPMENT OF X7050 ALLOY

In previous reviews, programs underway at the Alcoa Research Laboratories with the objective of developing an alloy possessing high strength in thick sections, high resistance to stress corrosion, and good fracture toughness have been described. These programs, which were supported by the Naval Air Systems Command and by the Air Force Materials Laboratory, resulted in the development of an alloy designated X7050 having the nominal composition Al-6.0Zn-2.3Mg-2.3Cu-0.12Zr. Further development of this new alloy is underway at the Alcoa Research Laboratories under the sponsorship of both agencies.

In studies supported by the Naval Air Systems Command, the objectives are to evaluate die forgings to obtain more extensive data on mechanical properties, to optimize precipitation heat treatments, and to continue stress-corrosion studies initiated in the earlier programs.(2) In studies supported by the Air Force Materials Laboratory, the properties of X7050 alloy are to be compared with those of similar alloys developed by Kaiser Aluminum (7049) and in programs supported by the Air Force at Boeing and Reynolds Aluminum.(3) Although slightly different compositions were recommended as a result of the Boeing and Reynolds studies, the composition ranges overlap permitting one composition, designated BAR, to represent both. Analyses of the three alloys proposed for study in this program are shown in Table 1. Forgings will be prepared from these alloys and evaluated after heat treatment to permit a direct comparison of the three compositions. Data from both of these new programs should become available in a few months.

The fatigue properties of 2-inch-thick X7050 plate in two tempers have been determined at the Naval Air Development Center.(4) Unnotched axially loaded specimens were cut parallel to the transverse direction of the plate and tested at a stress ratio of R = 0.25. The properties of this material are given in Table 2.

FRACTURE TOUGHNESS OF Al-Zn-Mg-Cu ALLOYS

A study of compositional variables affecting fracture toughness of high-strength aluminum alloys is underway at the Royal Aircraft Establishment, England. The importance of iron content on the toughness of DTD 5024 (Al-5.8Zn-2.5Mg-0.7Cu-0.3Mn) is discussed in a report describing one portion of this study.(5) As shown in Figure 1, the fracture toughness of this alloy decreases with increasing iron content. Reducing the iron content below the normal 0.3 percent level is beneficial to fracture toughness, especially in the transverse and short-transverse directions. The tensile properties of this alloy also are affected to some degree by iron content, as shown by the longitudinal tensile properties given below:

Iron Content, percent	Ultimate Tensile Strength, ksi	0.2% Offset Yield Strength, ksi	Elongation, percent
0.05	74.3	70.3	5.0
0.30	78.4	71.7	12.0
0.75	73.3	65.5	3.5

These data show that the normal iron content results in superior strength and ductility.

TABLE 1. ALLOYS TO BE EVALUATED IN THE ALCOA PROGRAM[3]

Alloy Designation	Composition, weight percent									
	Zn	Mg	Cu	Zr	Cr	Mn	Fe	Si	Ti	Ni
X7050	5.90	2.30	2.48	0.11	0.00	0.00	0.05	0.05	0.01	0.01
7049	7.87	2.61	1.46	0.00	0.15	0.00	0.06	0.04	0.02	0.00
BAR*	6.50	2.36	1.23	0.12	0.00	0.08	0.07	0.04	0.02	0.00

* Boeing-Air Force-Reynolds experimental conposition.

TABLE 2. FATIGUE STRENGTH OF X7050 ALLOY[4]

	Tensile Properties			Fatigue Strength, ksi	
Temper	Ultimate Tensile Strength, ksi	0.2% Offset Yield Strength, ksi	Elongation, percent	10^6 Cycles	10^7 Cycles
T7X1	81.8	74.5	10	44	39
T7X2	73.4	63.2	11	45	41

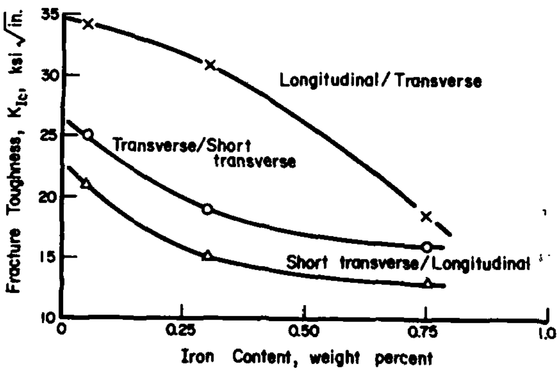

FIGURE 1. THE EFFECT OF IRON CONTENT UPON FRACTURE TOUGHNESS OF HEAT TREATED Al-Zn-Mg-Cu ALLOY DTD 5024

The lower fracture toughness observed in high-iron alloys is attributed to fracturing of aluminum-iron particles located in a stringered pattern as a result of working. Intergranular fracture was most extensive in low-iron material, indicating that iron does not affect fracture toughness by promoting intergranular failure. The pronounced anisotropy of fracture toughness was attributed to grain shape in low-iron material and to both grain shape and iron-phase distribution in normal and high-iron material.

Additional information on microstructural features affecting fracture behavior of high-strength alloys is provided by studies conducted at Olin Aluminum and published recently in Metallurgical Transactions.[6]

In this program, 7075 alloy was solution heat treated and precipitation hardened according to a variety of schedules to provide a wide range of microstructures and mechanical properties. Correlation of fracture behavior with microstructure suggested the following conclusions:

(1) The toughness of aged 7075, as measured by crack propagation energy, decreases as yield stress increases

(2) At the same yield stress, the underaged structure has greater toughness than the overaged structure

(3) There is a transition from predominantly transgranular fracture to predominantly intergranular fracture with increasing aging time

(4) Both transgranular and intergranular fracture proceed by dimple-rupture processes. The transgranular dimples are nucleated at the interfaces of chromium-rich dispersed particles. Intergranular dimples are nucleated at the interface of grain boundaries of $MgZn_2$ particles

(5) The fracture-mode transition from underaged to overaged structures may be correlated to a decrease in the intergranular fracture stress due to coarsening of the grain-boundary precipitates

(6) The fracture of 7075 is not primarily controlled by either precipitate-free zone width or the nature of the matrix precipitate.

STRESS-CORROSION-FATIGUE OF HIGH-STRENGTH ALUMINUM ALLOYS

Forged aluminum parts used in various aircraft components (e.g., landing gear) are exposed

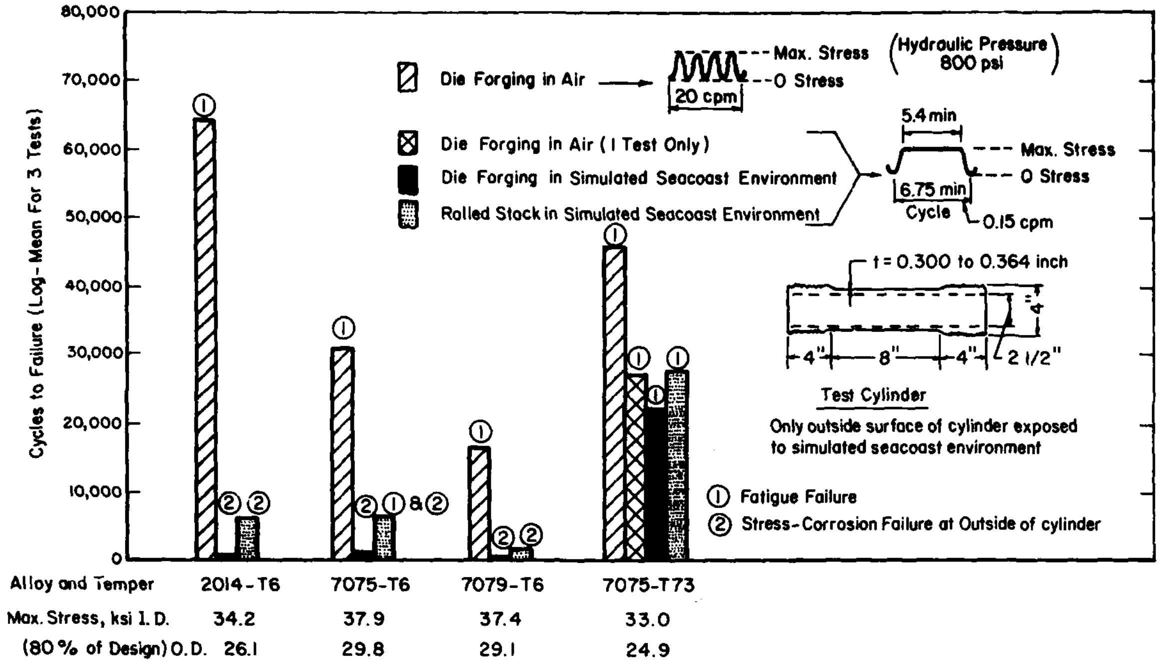

FIGURE 2. EFFECT OF ENVIRONMENT ON FATIGUE LIFE OF HYDRAULIC CYLINDERS(7)

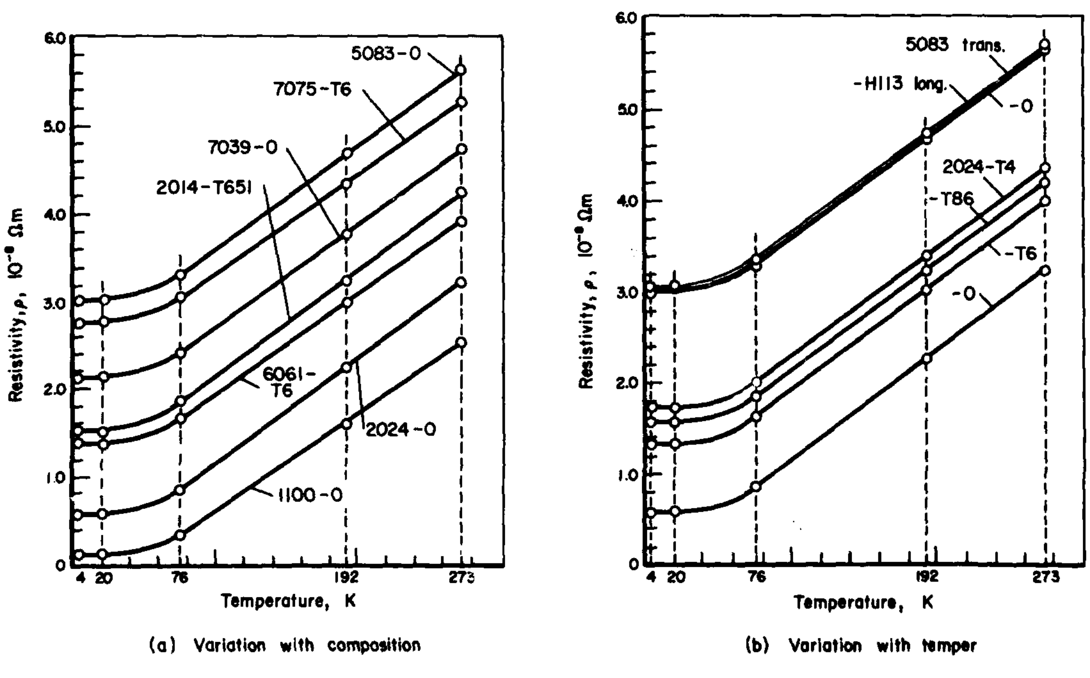

FIGURE 3. ELECTRICAL RESISTIVITY OF ALUMINUM ALLOYS AT LOW TEMPERATURE(8)

to service under conditions where fatigue and stress-corrosion processes may occur during successive portions of the service life. Corrosion-fatigue studies in which specimens are stressed continuously in a corrosive environment do not provide adequate information regarding the effects of alternate exposure to stress corrosion and fatigue (or corrosion fatigue). In the latter type of service, stress-corrosion cracking may occur during static exposure under load, followed by accelerated crack growth when cyclic stressing is resumed at intermittent intervals such that failure occurs in shorter periods than would be anticipated from either fatigue or stress-corrosion studies. A program to provide information on this failure process, designated "stress-corrosion-fatigue", has been conducted at the Alcoa Research Laboratories.(7) Materials examined in this program included 2014-T6, 7075-T6, 7075-T73, 7079-T6, 7078-T7, and the casting alloy CH70-T7. In addition to conventional stress-corrosion, fatigue, and corrosion-fatigue tests, tests were conducted on specimens that were fatigue loaded in a corrosive environment using a modified loading cycle such that 80 percent of the time of each load cycle consisted of a hold period at maximum stress. These tests also might be considered as stress-corrosion tests in which the stress was periodically removed. At the lowest fatigue test frequency, specimens were exposed to a constant maximum load for 5.4 minutes of each cycle and cycled through minimum load and back to maximum load in about 1.4 minutes.

The type of behavior observed in hydraulically loaded cylinders of four materials is shown in Figure 2. In three of these materials exposed to stress-corrosion-fatigue, failure occurred by stress-corrosion-crack formation on the salt-fog exposed surface in relatively few cycles as compared with the static fatigue life. Alloy 7075-T73, on the other hand, seemed unaffected by the presence of salt fog. In this latter case, of interest to note is the appreciable reduction in fatigue life resulting from the static-load period in the absence of an obvious corrosion contribution to failure. Fatigue failures initiated on the interior surfaces of the hydraulically loaded cylinders in all cases.

Stress-corrosion tests showed 7075-T73 alloy to be relatively immune to cracking as compared with 7075-T6. The former lasted 15 months without cracking under conditions causing failure by stress corrosion in 7 to 8 days in the latter. The corrosion-fatigue behavior of these two materials as measured by using normal procedures was essentially the same, however.

Alloys X7080-T7 and CH70-T7 also were found to be quite resistant to stress-corrosion attack and to failure under fatigue loading with concurrent static exposure at maximum load. However, they were less resistant than 7075-T73.

Specimens of these alloys were also tested for fatigue behavior, stress-corrosion resistance, and stress-corrosion-fatigue behavior using C-ring-type specimens. Differences in behavior between these tests and the cylinder tests were observed and were attributed to differences in loading conditions (constant stress versus constant strain).

RESISTIVITY OF ALUMINUM ALLOYS AT LOW TEMPERATURES

Measurements of the electrical resistivity at low temperatures of a number of alloys have been published recently by the National Bureau of Standards.(8) Data for aluminum alloys included in this investigation are given in Figure 3. Of interest is the uniformity of shape of all resistivity-temperature curves shown in this figure. The authors conclude that the low-temperature resistivity of any aluminum alloy can be quite reliably extrapolated from a room-temperature measurement.

IMPROVING THE PROPERTIES OF 7079 ALLOY

The effects of heat treatment on the properties of 7079 alloy forgings have been examined in an effort to design a treatment that will result in improved stress corrosion behavior with minimum detriment to other mechanical properties.(9) Variables studied included duration of solution heat treatment, temperature of the quench bath, primary aging treatment, and secondary aging treatment. Heat treatment was concluded to affect properties in two groups; strength properties (tensile strength and fatigue strength) and crack tolerance properties (fatigue crack-propagation resistance, fracture toughness, and stress-corrosion resistance). Those treatments that improve one group of properties are usually detrimental to the other. The behavior observed can be explained by considering the effects of heat treatment on microstructure. The optimum heat treatment is believed to include both hot-water quench (175 F) and a high secondary aging temperature (320 F for 15 hours) to provide good crack resistance and a relatively high primary aging temperature (175 to 210 F for 15 hours) to provide adequate strength.

FATIGUE PROPERTIES OF KO-1 CASTINGS

Fatigue data for KO-1 casting alloy have been determined by Northrop.(10) Fatigue specimens ($K_t = 3$) were machined from castings heat treated to either the T6 or the T7 temper and tested in axial loading using an R value of either 0.2 or -1.0. The results of tests at R = 0.2 are presented in Figures 4 and 5. Tensile properties of these coatings were reported as follows:

	Ultimate Tensile Strength, ksi	0.2% Offset Yield Strength, ksi	Elongation, percent
KO-1-T6	67.9	58.4	8
KO-1-T7	65.7	62.7	3

EFFECT OF PROLONGED ELEVATED TEMPERATURE EXPOSURE ON THE FATIGUE PROPERTIES OF TWO ALUMINUM ALLOYS

The properties of two aluminum alloys, clad 2024-T81 and solution treated and aged RR 58 (a British alloy similar to 2618-T6) after about three years exposure at 250 or 300 F are reported in a recent NASA publication.[11] Fatigue properties were determined using both unnotched and notched (K_t = 4) specimens prepared from 0.063 inch sheet. Tensile properties of these two alloys were relatively unaffected by prolonged exposure at 250 or 300 F, as shown in Table 3. Fatigue properties also were found to be unaffected by thermal exposure. Maximum exposure times examined were:

	250 F	300 F
Clad 2024-T81	26,300 hours	17,500 hours
Clad RR58(-T6)	26,300 hours	8,800 hours

Fatigue results for clad RR58 exposed for 26,300 hours at 250 F are given in Figure 6. Axial-load fatigue tests were run using a constant mean stress at 13 ksi and a frequency of 1800 cpm.

MAGNESIUM CASTING ALLOY ZE63A

Information prepared by Magnesium Elektron Limited has been released describing a high-strength magnesium sand casting alloy designated ZE63A.[12] The nominal composition of this alloy is 5.8 percent zinc, 2.5 percent rare earth (cerium), and 0.6 percent zirconium. The attainment of full strength requires solution heat treatment and aging (T6) The solution heat treatment is conducted using a proprietary process involving hydrogen. Details of this treatment are available from Magnesium Elektron. Properties of this alloy are summarized in Table 4. The alloy is claimed to have excellent casting properties and to be useful for service to about 350 F.

ELECTROPLATING MAGNESIUM ALLOYS

Electroplated coatings are applied to magnesium alloys (1) for decorative purposes, (2) for improving crack or corrosion resistance, and (3) for protection against galvanic corrosion where contact with dissimilar metals is anticipated. A review of electroplating of magnesium alloys has been published recently in Metal Finishing.[13] This review provides considerable information on plating methods, including a step-by-step discussion of current practices. Comments on the advantages and economics of various plating procedures also are presented.

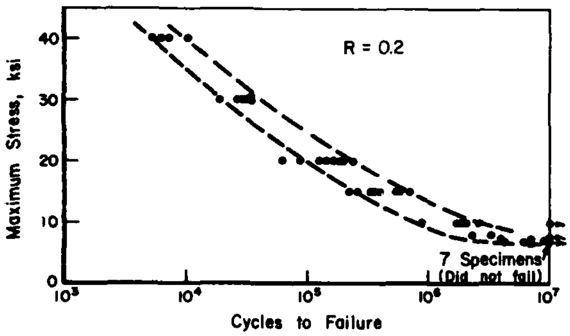

FIGURE 4. NOTCHED (K_t = 3) FATIGUE PROPERTIES OF KO-1-T6[10]

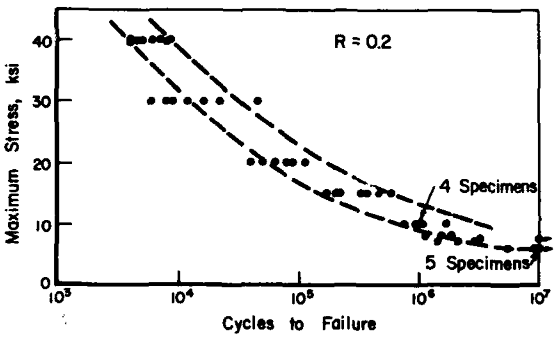

FIGURE 5. NOTCHED (K_t = 3) FATIGUE PROPERTIES OF KO-1-T7[10]

TABLE 3. TENSILE PROPERTIES OF TWO ALUMINUM ALLOYS AS AFFECTED BY THERMAL EXPOSURE[11]

		Clad RR 58-T6			Clad 2024-T81		
Temperature, F	Time, hours	Ultimate Tensile Strength, ksi	Yield Tensile Strength, ksi	Elongation, percent	Ultimate Tensile Strength, ksi	Yield Tensile Strength, ksi	Elongation, percent
--	--	59.5	53.8	7	64.6	57.5	7
250	2,200	59.0	54.0	7	64.9	57.8	7
	4,400	59.2	54.2	7	65.0	58.5	7
	8,800	59.6	54.2	7	65.5	58.4	7
	17,500	59.3	54.3	8	64.2	57.3	8
	26,300	59.0	51.7	7	62.3	52.4	8
300	2,200	58.3	52.5	8	62.0	53.2	8
	4,400	57.5	50.9	8	62.1	53.2	7
	8,800	56.7	49.8	8	60.6	51.1	7
	17,500	--	--	--	59.9	50.2	8

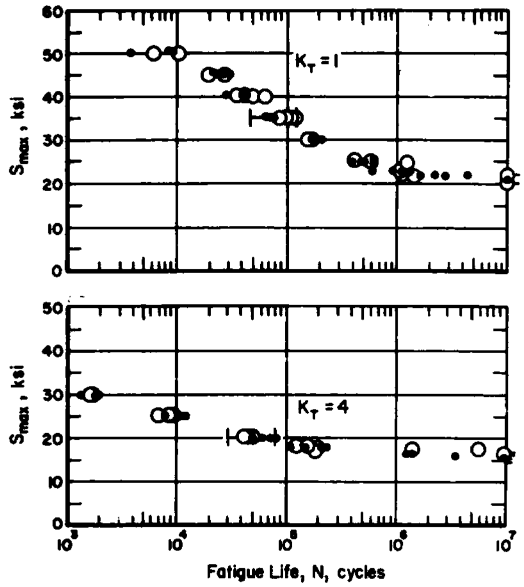

FIGURE 6. EFFECT OF THERMAL EXPOSURE AT 250 F ON THE FATIGUE PROPERTIES OF CLAD RR58(-T6) ALLOY(11)

○ No exposure; • 26,300 hours of exposure

TABLE 4. PROPERTIES OF MAGNESIUM CASTING ALLOY ZE63A-T6(12)

Density	1.87 gm/cm^3
Modulus of Elasticity	6.4 x 10^6 psi
Ultimate Tensile Strength	40.6 ksi
0.2 Offset Tensile Yield Strength	29.1 ksi
Tensile Elongation	8 percent
Unnotched Fatigue Strength, 5 x 10^7 Cycles	17.5 ksi[a]
Fracture Toughness, K_{Ic}	19 to 24.5 ksi$\sqrt{\text{in.}}$

(a) Rotating beam tests.

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